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DESIGN OF TREATMENT PLANTS FOR LOW TURBIDITY WATER

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SANITARY ENGINEERING DIVISION

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DESIGN OF TREATMENT PLANTS FOR LOW TURBIDITY WATER

Roy H. Ritter,[1] M.ASCE

General Considerations

The design features of modern water purification plants for handling low turbidity water are substantially the same as those for handling other types of surface waters. It is customary to provide flash mixing, mechanical flocculation and sedimentation basins to properly prepare the water for filtration.

Recent trends indicate that mechanically cleaned sedimentation basins are desirable in plants treating low turbidity water. Quite a number of existing plants handling low turbidity water still have manually cleaned basins. The cost of the relatively infrequent cleaning does not completely justify the installation of mechanical cleaning equipment in existing basins. The labor cost of manually cleaning sedimentation basins of 6 Mgd capacity at the 37th Street Plant in Norfolk, Virginia, is $120 per year. Basins are cleaned once every five weeks by a three man crew working four hours. The basins are out of service for about 24 hours for each cleaning, which is 2.8 per cent of the time. Mechanical cleaning equipment costs 1.25 per cent of the total plant cost at the new Ashburton Filtration Plant now under construction in Baltimore, Maryland. There are factors other than first cost and labor, but in general it is economical to provide mechanical cleaning equipment in new plants. Of course, the cost of installing mechanical cleaning equipment in existing basins is considerably more than when incorporated in the original design. The justification of mechanical cleaning equipment in sedimentation basins for low turbidity waters depends upon the frequency of cleaning and the necessity to have all basins in continuous operation during periods of peak summer demand.

In general modern water plants are using fewer but larger filter units. The recent practice established by Chicago of operating the filters at 3 gals./sq. ft./min. or higher has influenced the uprating of existing filter plants. For instance, a filter plant of 10 million gallons nominal capacity at 2 gals./sq.ft./min. of filter area should be able to supply 10 Mgd yearly average of water and take care of the customary summer time peak loads. This, of course, depends upon the peculiarities of the peak demands in each municipality since peak days will vary from 130% in one city to almost 200% of the yearly average in another city.

Sedimentation basins, designed for approximately the customary four hours of detention, can usually take an increased rate of flow if sufficient amount of alum is added. This may decrease the filter runs during periods of high demand. However, it is not economically sound to design a filter plant at the normal rate on the basis of the maximum daily use. The additional cost of extra alum during periods of maximum use is justified as compared with the cost of making the entire filter plant appreciably larger.

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A study has been made of two filter plants in Norfolk, Virginia, and one in Baltimore, Maryland, treating low turbidity waters. It is believed that graphical presentation of actual records of existing plant operations will add to the general knowledge concerning the design features of water purification plants.

In general, these studies indicate that below a turbidity of a certain amount the alum dosage is not affected by turbidity; whereas, above this particular amount, which varies for each plant, alum dosage is affected by turbidity. This critical amount of turbidity has been given the suggested designation of "threshold turbidity."

As would be expected, the studies indicate that alum dosage increases as the detention time decreases and also that alum dosage increases as the overflow rate increases. These trends are confirmed by repeated analyses of operating data.

In waters with an appreciable amount of color, the effect of turbidity is sometimes lost and the amount of color alone determines the amount of alum use. In fact, the alum dosage at the 37th Street Plant at Norfolk is controlled by color practically all of the time and rarely does turbidity affect its operation.

The following tables and charts illustrate the investigations of the three large plants which have been studied, and design data is shown for the Ashburton Plant now under construction in Baltimore.

Table 1 shows the design features of four plants for low turbidity water. Changing design features from 1910 to 1950 is demonstrated by the lack of rapid mixing and mechanical flocculation in the early plants. In fact, these features were added to the 37th Street Plant at Norfolk about 1940. Larger filter units are now more generally used throughout the country for both high and low turbidity waters than were formerly installed.

The average design detention of the four plants in Table 1 is 3.5 hours or slightly less than the customary four hours for sedimentation. None of these plants is now operating at capacity, although the 37th Street Plant during the war produced 33 Mgd or 37 per cent overload for a period of several weeks and was operated at 30 Mgd or 25 per cent overload for a period of over a year.

The overflow rate varies, in these four plants, from 400 to 920 gals./sq./ft./day which is the customary range for most water plants.

Table 2 shows the turbidity variations at the Montebello Plant in Baltimore. The average raw water turbidity for 14 years was only 8 ppm or less than the 10 ppm U.S. Public Health Service standard for drinking water. The maximum monthly average was 19 ppm; however, as would be expected, individual daily maximums averaged three times the maximum monthly average.

Similar variations in turbidity should be expected in comparable water supplies.

Chart No. 1 shows the monthly variations of the three typical low turbidity waters during the 14 year period 1939 to 1953. Turbidity at the Moores Bridges Plant in Norfolk was less than 100 ppm 99 per cent of the time and 95 per cent of the time the turbidity was less than 50 ppm. At the 37th Street Plant in Norfolk turbidity has never exceeded 100 ppm, and 95 per cent of the time the turbidity was less than 10 ppm. Unusual circumstances led to the high turbidities at Moores Bridges from 1941 to 1944. Water demand increased sharply during the war years, and it was necessary to pump water from Lake Drummond, an inferior supply in the Dismal Swamp area. Additional sources have been developed since, and such high turbidities will not recur.

At the Montebello Plant in Baltimore the monthly average turbidity never exceeded 50 ppm; 95 per cent of the time it was less than 17 ppm.

TABLE NO. 1

DESIGN FEATURES OF WATER PLANTS WITH LOW TURBIDITY WATER

	Baltimore, Md.		Norfolk, Va.	
	Montebello	Ashburton	Moores Bridges	37th Street
	Impounded Supplies		Shallow Lake	Impounded Supply
APPROX. DESIGN DATE	1910 and 1925	1952	1950	1925
NOMINAL CAPACITY	240 Mgd	120 Mgd	24 Mgd	24 Mgd
AVERAGE 1953 USE	200 Mgd	-	20 Mgd	20 Mgd
RAPID MIXING	None	None (possible future)	Flash Mixers	Flash Mixers
SLOW MIXING	Over and Under and around end baffles 33 Min.	Around End baffles 10 Min.	None	None
FLOCCULATION	None	Transverse Paddles 45 Min.	Walking Beam 51 Min.	Longitudinal Paddles 25 Min.
SEDIMENTATION	4 around end basins	4 straight through basins	4 straight through basins	4 around end basins
Detention	3.2 hours	3.6 hours	3.0 hours	4.0 hours
Overflow Rate	730 Gal/sqft/day	920 Gal/sqft/day	830 Gal/sqft/day	400 Gal/sqft/day
Average Velocity through basins	1.3 ft/min.	0.84 ft/min.	0.5 ft/min.	1.7 ft/min.
FILTERS	60 at 4 Mgd	20 at 6 Mgd	4 at 3 Mgd 6 at 2 Mgd	24 at 1 Mgd
AVERAGE RAW WATER CHARACTERISTICS				
Turbidity	8 ppm	-	21 ppm	5 ppm
Color	7 ppm	-	50 ppm	60 ppm
pH	7.1	-	7.1	6.8
Alkalinity	35 ppm	-	28 ppm	28 ppm

TABLE NO. 2

MONTEBELLO FILTRATION PLANT
BALTIMORE, MARYLAND

TURBIDITY VARIATIONS

Year	Average Turbidity	Max. Day	Min. Day	Max. Month	Ratio Max.Day / Max. Month
1939	11	35	4	21	1.66
1940	12	55	3	20	2.75
1941	6	15	3	11	1.36
1942	11	44	4	18	2.44
1943	8	100	2	20	5.00
1944	9	85	3	28	3.03
1945	6	25	3	9	2.78
1946	10	60	2	41	1.46
1947	4	14	2	7	2.00
1948	4	150	1	9	16.70
1949	4	8	3	5	1.60
1950	5	30	3	15	2.00
1951	10	160	2	48	3.34
Average	8	60	2.7	19	3.16

This chart illustrates the very low and fairly uniform turbidities of surface water supplies having large impounding reservoirs.

Chart No. 2 shows the turbidity and alum dosage of the Montebello Plant at Baltimore for years 1930 to 1951. The water supply at this plant is from impounding reservoirs providing approximately 200 days of storage on the average. There is practically no color in the water, although at times manganese in the spring and fall does create a treatment problem. This chart shows that there is a definite trend of increased alum dosage as the raw water turbidity increases, varying from about 0.5 grain per gallon with low turbidities of 4 ppm and increasing to about C.9 grain per gallon for yearly average turbidity of about 20 ppm.

Chart No. 3 shows the yearly average turbidity, color and alum at the Moores Bridges Water Plant in Norfolk, Virginia, for the years 1939 to 1952. The water supply to the plant is from nearby shallow lakes where the average annual color is approximately 50 ppm. The turbidity is approximately 21 ppm and varies with the color. The chart demonstrates that the alum dosage

generally increases with both turbidity and color at this particular plant.

During the war years this plant used water from Drummond Lake in the Dismal Swamp area which had unusually high color and turbidity. It must be remembered that the use of alum is determined by the plant chemist who must exercise his judgment and use a sufficient amount to maintain a standard high quality of water reaching the city system.

Chart No. 4 shows the turbidity, color and alum at the 37th Street Water Plant at Norfolk, Virginia, from the years 1939 to 1952. This plant has an average color of about 60 ppm but a raw water turbidity of only 5 ppm. The source of supply for this plant is from large reservoirs into which several cypress swamps drain which accounts for the very high color.

It will be noted that alum dosage follows the trend of the color. The fact that the peak color year of 1945 does not coincide with the peak alum year of 1946 cannot be explained except by other items of special plant operation during this period.

Charts Nos. 3 and 4 on low turbidity waters indicate that alum use does follow turbidity, where turbidity predominates, but color in the water is the controlling factor when turbidity becomes appreciably low.

Chart Nos. 5 and 6 were prepared to compare the variations in alum dosage with (1) overflow rate, (2) turbidity and (3) color.

The detention time is also indicated on an adjacent curve, but, of course, detention is inversely proportional to overflow rate.

Chart No. 5 shows 3 month moving averages of these items at the Montebello Plant in Baltimore from 1945 to 1951.

As would be expected in periods of high turbidity, the alum dosage parallels very closely the turbidity curve. At this time the overflow rate apparently had only a minor effect upon the alum dosage.

During the several years of low turbidity, averaging about 5 ppm, the alum dosage followed very closely the overflow rate. The percentage increase in alum dosage was approximately the same as the percentage increase in the overflow rate. During this period the detention was about 4 hours varying from about 3-1/2 hours to 4-1/2 hours, since the plant was not operated at its full capacity.

Chart No. 6 shows 3 month moving averages of turbidity, detention, overflow rate and alum at the 37th Street Water Plant at Norfolk, Virginia, during the years 1951 to 1953.

On the upper curve showing the detention, the monthly averages are shown in rectangular blocks and the solid curve indicates the 3 month moving averages of the monthly averages.

In the Summer of 1951, when the turbidity and color were fairly uniform, the alum dosage increased identically with the increase in overflow rate which resulted from the lesser detention during periods of high summer time demands.

Although the overflow rate decreased in the Spring of 1952, when the turbidity and color were also uniform, the alum rate increased. This is contrary to what would be expected and was undoubtedly due to other causes than those shown on the chart.

In the Spring of 1953 with slightly higher than average color, low turbidity and low overflow rate, the alum use was the lowest. This demonstrates that, regardless of color, the low overflow rates permitted a reduction in alum dosage.

Charts Nos. 7, 8 and 9 were prepared to show that alum dosage does not follow turbidity below a certain value which for the purpose of this paper is called "Suggested Threshold Turbidity."

Chart No. 7 shows the alum use with respect to raw water turbidity for the years 1930 to 1951 at the Montebello Plant in Baltimore, Maryland. The same trend line shown on Chart No. 2 is reproduced on this chart. It will be observed that below the suggested threshold turbidity of 10ppm, there apparently is no uniformity or trend of alum dosage with respect to turbidity. There is practically no color in the impounded water at Baltimore.

Chart No. 8 shows the alum dosage with respect to raw water turbidity at the Moores Bridges Water Plant in Norfolk, Virginia, for the years 1939 to 1953. The suggested threshold turbidity at this plant is about 30 ppm since below this amount there appears to be no relationship between turbidity and alum dosage. It is impossible to place a trend line on this chart, which shows only alum and turbidity, the reason being that color and overflow rate have a predominant control of alum usage at this plant.

Chart No. 9 shows the alum dosage with respect to raw water turbidity at the 37th Street Plant in Norfolk, Virginia, for the years 1939 to 1953. Below the suggested threshold turbidity of 10 ppm, there appears to be no relationship between the amount of turbidity and alum dosage. Again this is due to color and overflow rate which control the amount of alum used at this plant.

The alum dosages used at each of these plants were as near to the optimum as can be obtained by qualified personnel using modern laboratory practices.

Chart No. 10 shows the monthly average settled water turbidity at the Montebello Plant in Baltimore for the 10 year period 1942-1951. During this period the settled water turbidity before filtration never exceeded 5 ppm and averaged about 3 ppm; whereas, the U.S. Public Health Service standard for drinking water after filtration is 10 ppm.

This chart shows one of the main reasons why rapid sand filters in many plants can be operated at higher than nominal rates and still produce water of excellent quality.

Upflow tanks with one or two hours detention have been used in plants with low turbidity waters and high degree of color. Activated silica appears to be necessary to form a sufficiently heavy floc or sludge to make this type of plant operate completely satisfactorily at all times. In general, low turbidity water, where the alum use is less than 3 grains per gallon, can be treated satisfactorily and economically in the conventional horizontal flow tanks. The plants at Norfolk and Baltimore have been able to operate at 50 per cent above nominal capacity by increasing alum dosage. However, in the future the use of activated silica may serve to assist in operating existing sedimentation basins under overload conditions to better prepare the water for filtration. Since the space needed for activated silica treatment is small, many modern plants are providing the space although the equipment is not necessarily installed.

This review of the operation of three large plants should be helpful in furnishing actual data, and in comparing the alum dosage with detention and overflow rates. The effect of alternate sizes of sedimentation basins on alum costs can be estimated. The designing engineer should analyze the alum requirements of the water to be treated because of the wide variations in character of all water supplies.

For those interested in more details of modern design filtration plants, reference is made to the excellent summary on water treatment practices prepared by the American Society of Civil Engineers entitled "Water Treatment Plant Design" as well as a companion volume prepared by the American Water Works Association entitled "Water Quality and Treatment" which describes practices throughout the United States.

CHART NO. 1

BALTIMORE AND NORFOLK WATER TREATMENT PLANTS

TURBIDITY VS. TIME

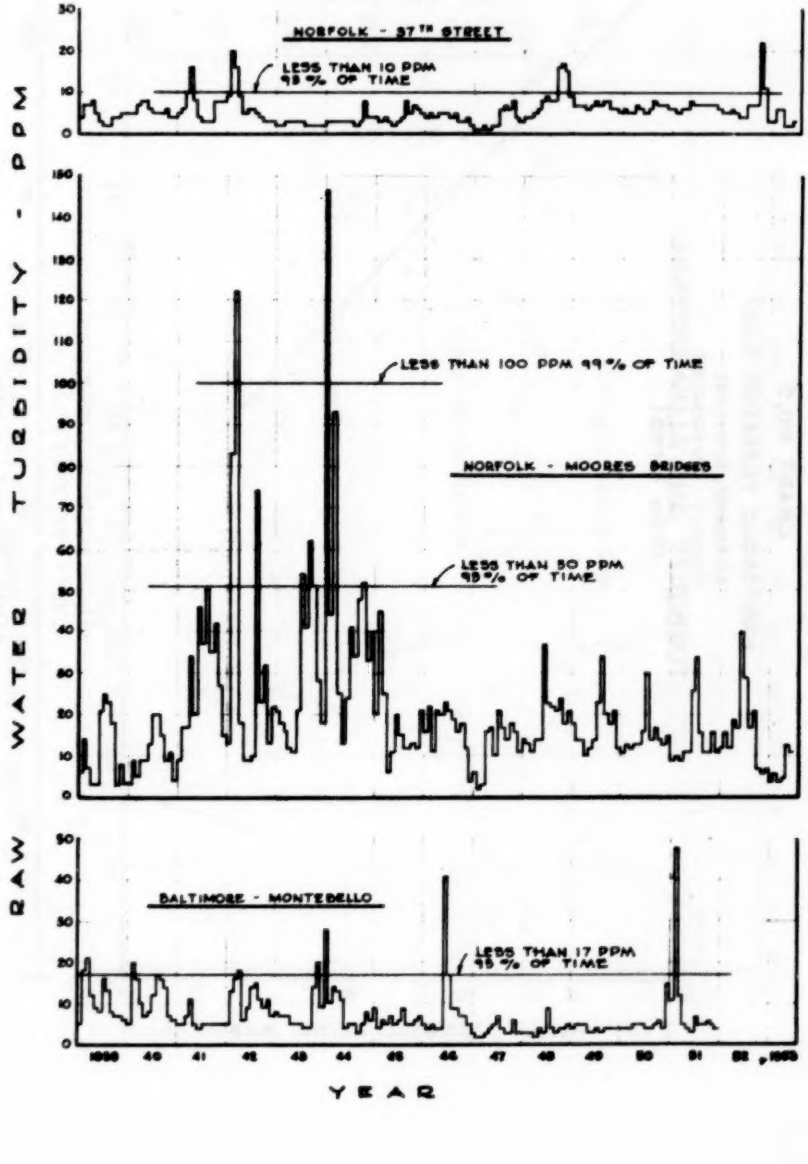


CHART NO. 2

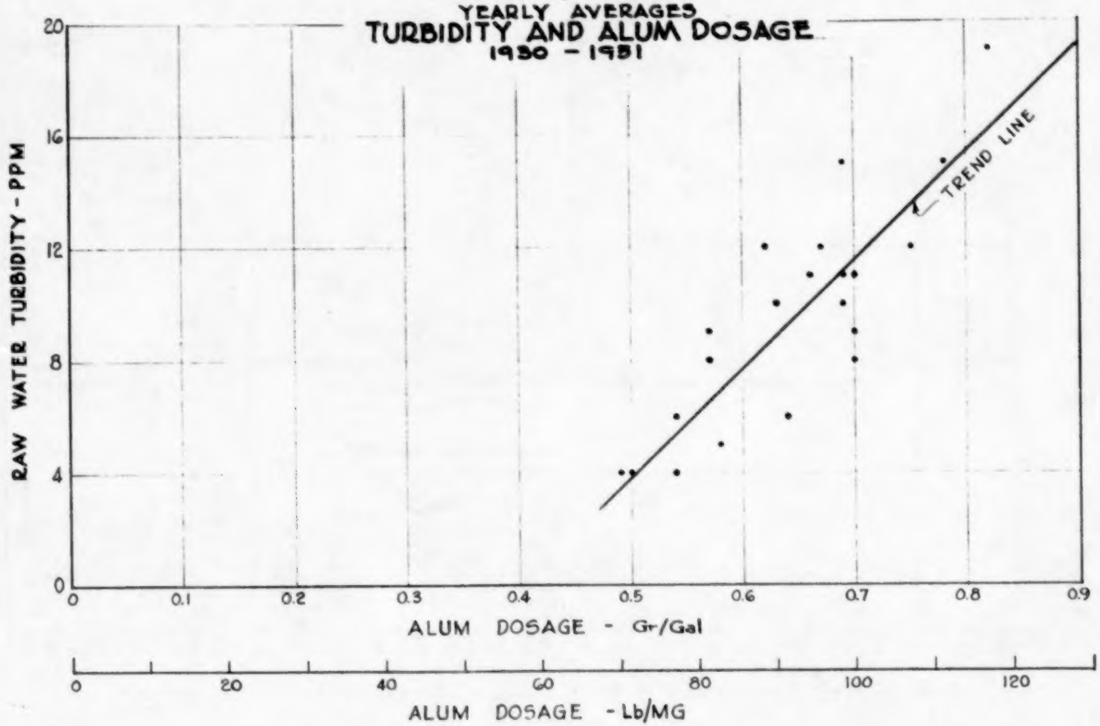
MONTEBELLO FILTRATION PLANT

BALTIMORE, MARYLAND

YEARLY AVERAGES

TURBIDITY AND ALUM DOSAGE

1930 - 1951



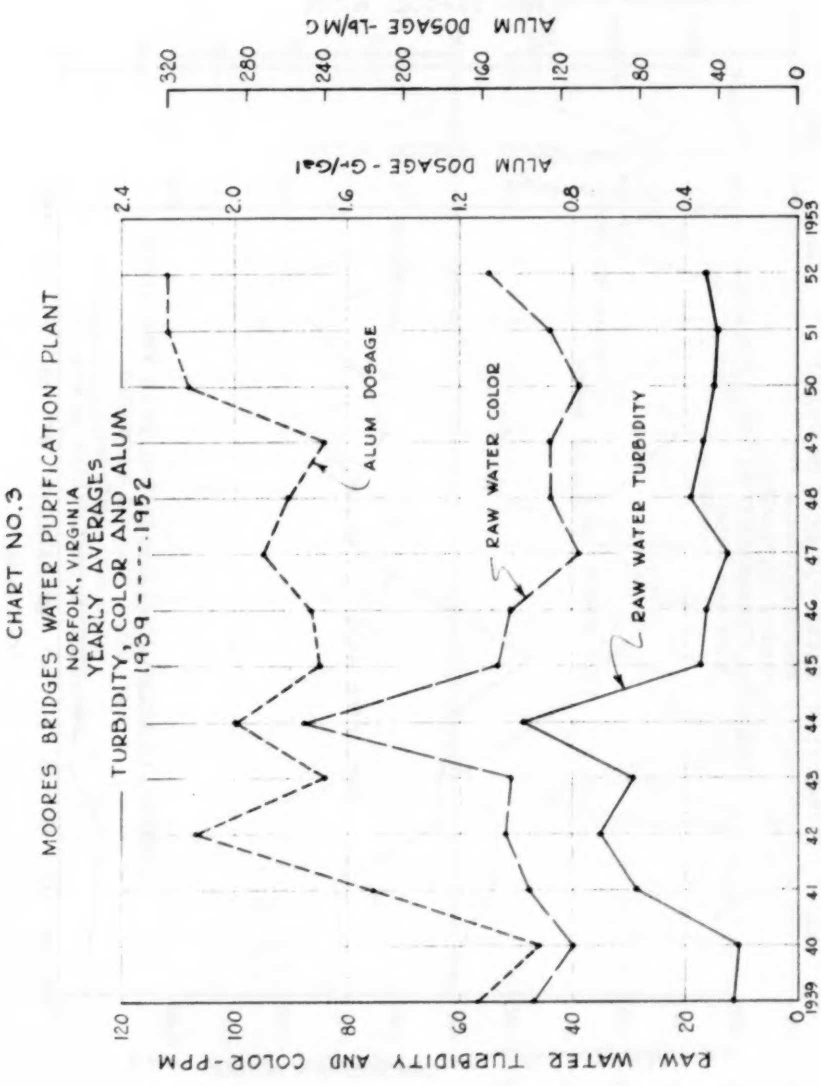


CHART NO.3
MOORES BRIDGES WATER PURIFICATION PLANT
NORFOLK, VIRGINIA
YEARLY AVERAGES
TURBIDITY, COLOR AND ALUM
1939 - - - -1952
ALUM DOSAGE
RAW WATER COLOR
RAW WATER TURBIDITY
RAW WATER TURBIDITY AND COLOR-PPM
0
20
40
60
80
100
120
ALUM DOSAGE - Gr/Gal
0
0.4
0.8
1.2
1.6
2.0
2.4
ALUM DOSAGE -Lb/MG
0
40
80
120
160
200
240
280
320
YEAR
1939
40
41
42
43
44
45
46
47
48
49
50
51
52
1953

CHART NO. 4
37TH STREET WATER PURIFICATION PLANT
NORFOLK, VIRGINIA
YEARLY AVERAGES
TURBIDITY, COLOR AND ALUM
1939 --- 1952

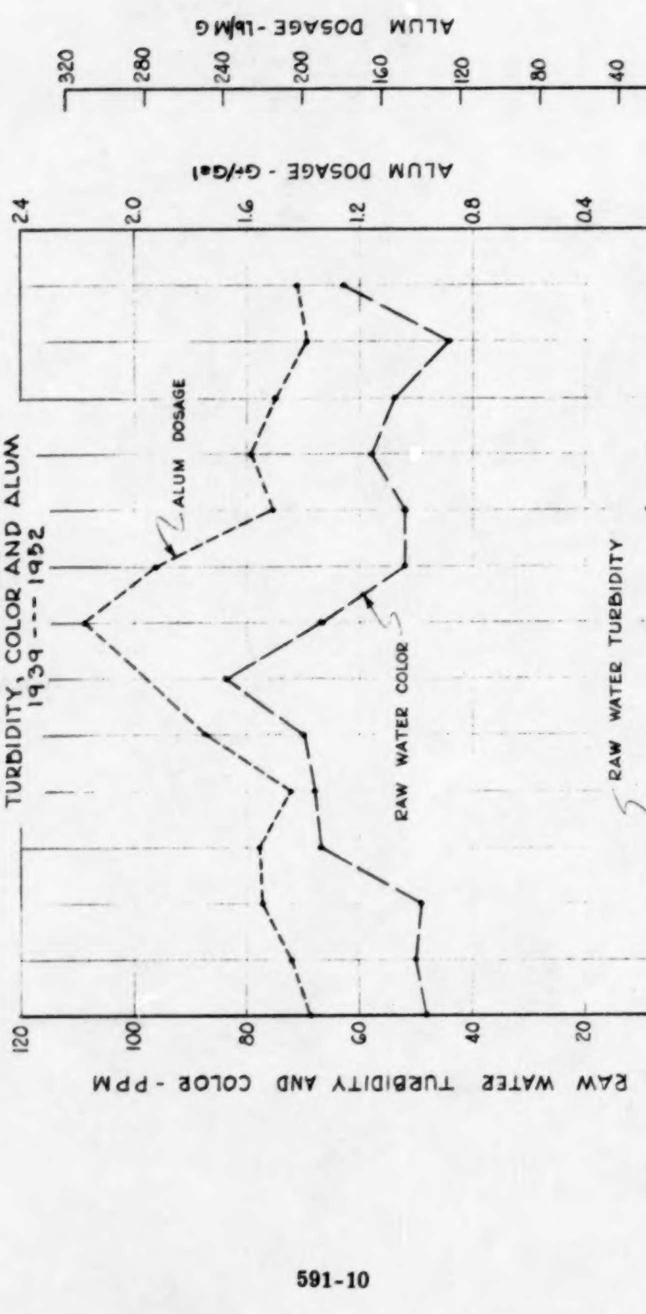


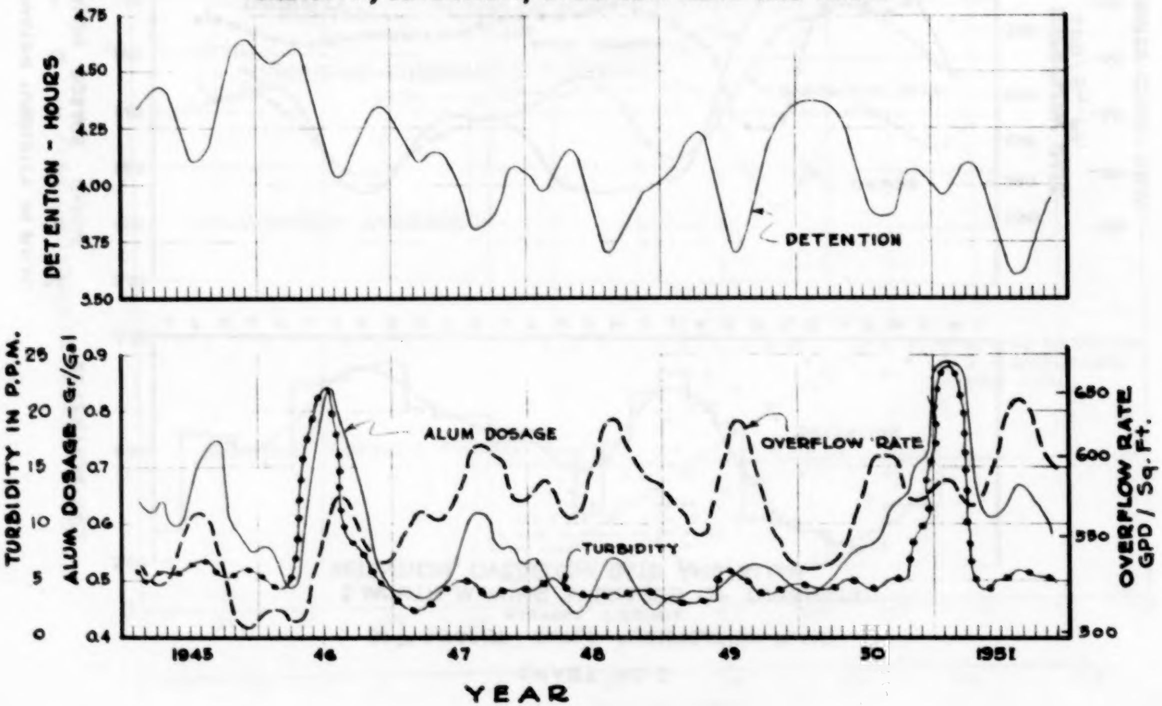
CHART NO. 5

MONTEBELLO FILTRATION PLANT

BALTIMORE, MARYLAND

3 MONTH MOVING AVERAGES

TURBIDITY, DETENTION, OVERFLOW RATE AND ALUM



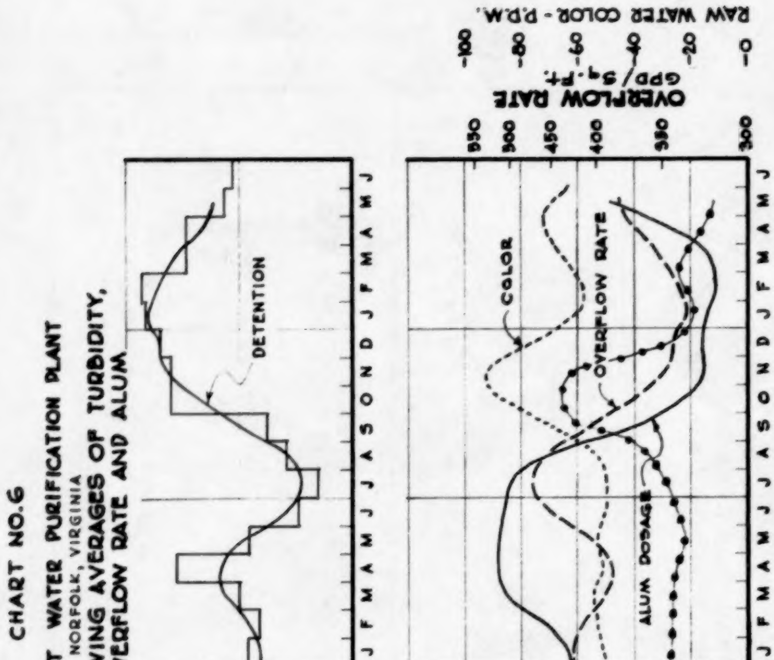


CHART NO.6
37TH STREET WATER PURIFICATION PLANT
NORFOLK, VIRGINIA
3 MONTH MOVING AVERAGES OF TURBIDITY, DETENTION, OVERFLOW RATE AND ALUM
DETENTION-HRS.
5.00
4.00
3.00
DETENTION
ALUM DOSAGE - Gr/Gal
2.00
1.80
1.60
1.40
1.20
1.00
0.80
RAW WATER TURBIDITY IN P.P.M.
24
20
16
12
8
4
0
OVERFLOW RATE
GPD/Sq.Ft.
550
500
450
400
300
RAW WATER COLOR - P.P.M.
100
80
60
40
20
0
COLOR
OVERFLOW RATE
ALUM DOSAGE
TURBIDITY
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J
1951
1952
1953

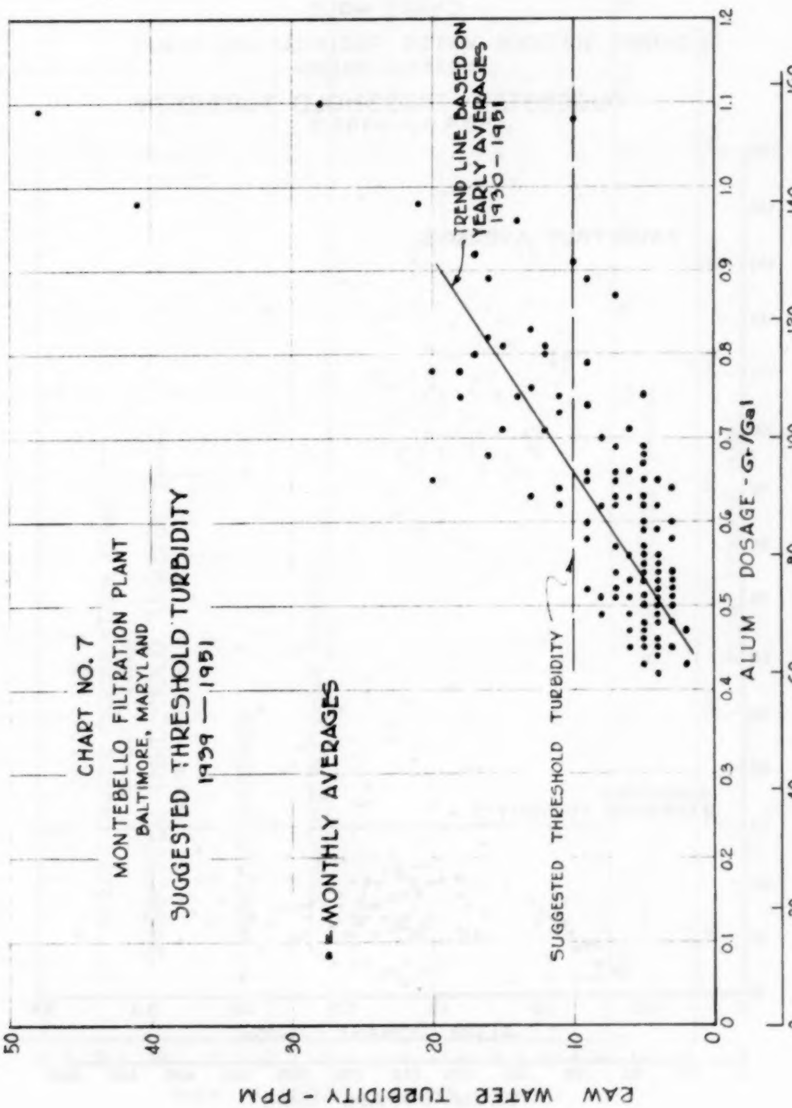
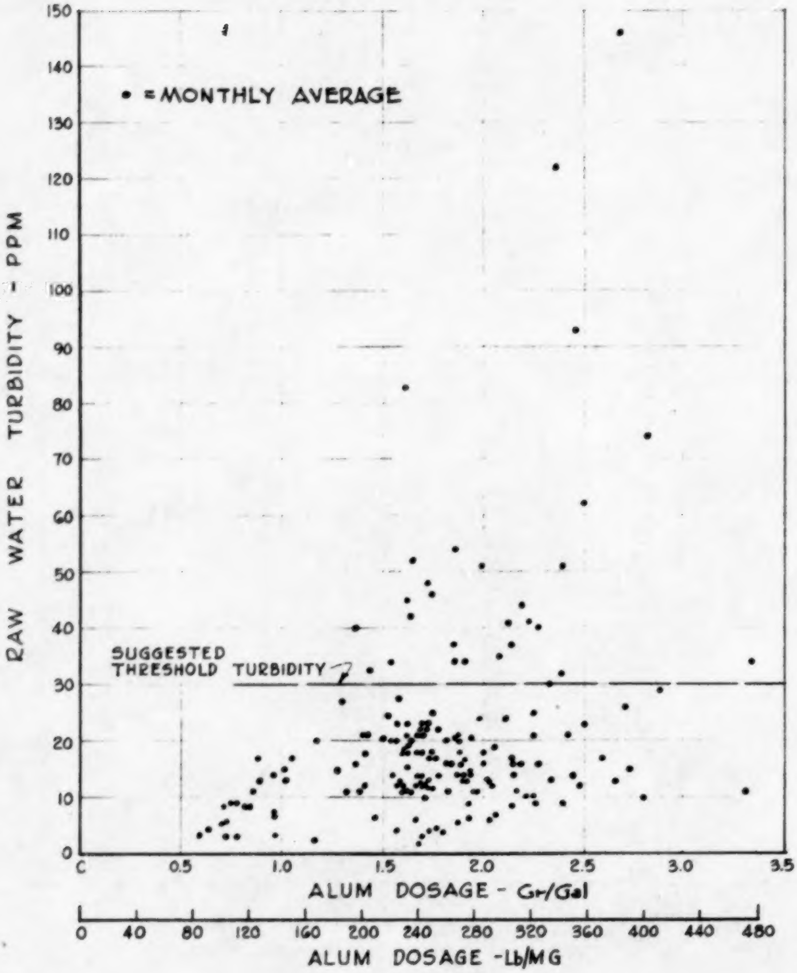


CHART NO. 7
MONTEBELLO FILTRATION PLANT
BALTIMORE, MARYLAND
SUGGESTED THRESHOLD TURBIDITY
1939 — 1951
• = MONTHLY AVERAGES
TREND LINE BASED ON YEARLY AVERAGES 1930 - 1951
SUGGESTED THRESHOLD TURBIDITY
RAW WATER TURBIDITY - PPM
ALUM DOSAGE - Gr/Gal
ALUM DOSAGE - Lb/MG
0
10
20
30
40
50
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
20
40
60
80
100
120
140
160

CHART NO. 8

MOORES BRIDGES WATER PURIFICATION PLANT
NORFOLK, VIRGINIA

SUGGESTED THRESHOLD TURBIDITY
1939 - - - 1953



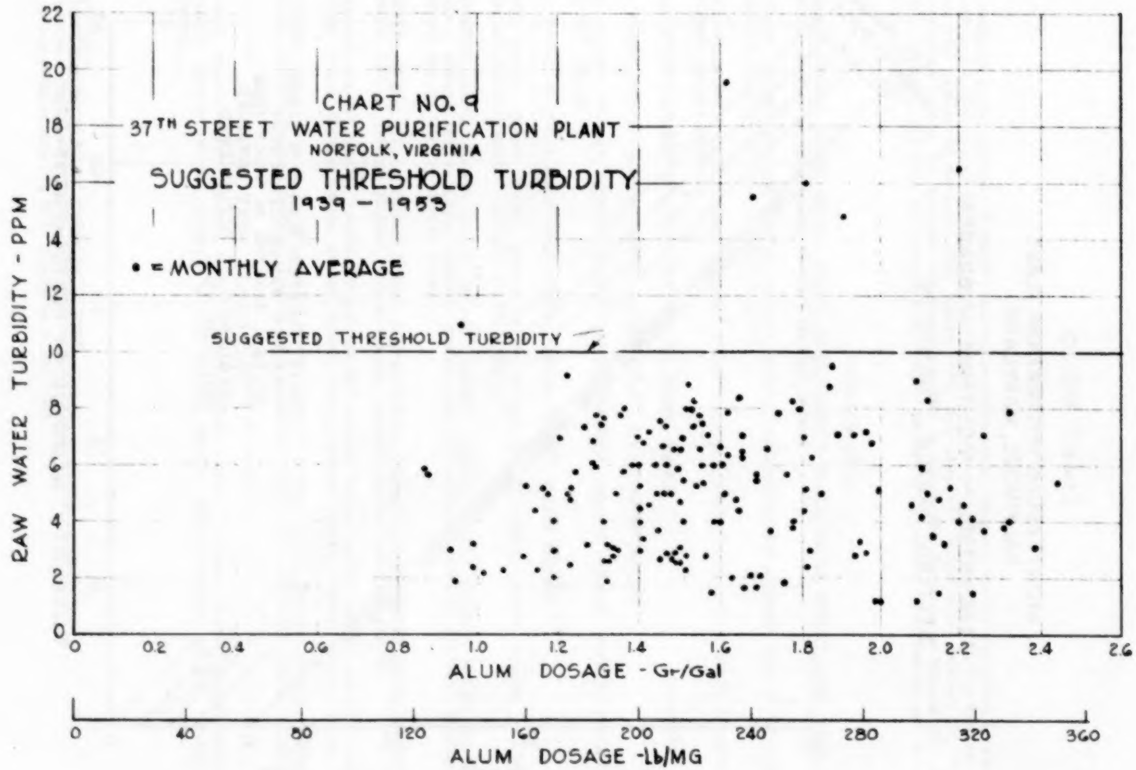
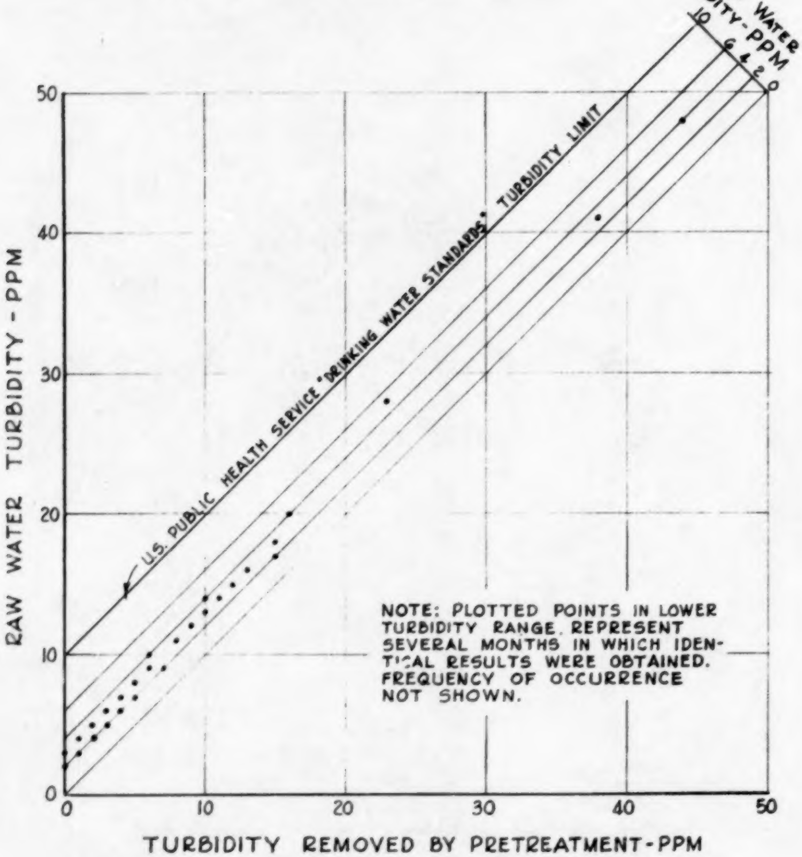


CHART NO. 9
37TH STREET WATER PURIFICATION PLANT
NORFOLK, VIRGINIA
SUGGESTED THRESHOLD TURBIDITY
1939 – 1953
• = MONTHLY AVERAGE
SUGGESTED THRESHOLD TURBIDITY
RAW WATER TURBIDITY - PPM
ALUM DOSAGE - Gr/Gal
ALUM DOSAGE -lb/MG

CHART NO. 10

MONTEBELLO FILTRATION PLANT
BALTIMORE, MARYLAND

1942 TO 1951 – MONTHLY AVERAGES
OF
SETTLED WATER TURBIDITY



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c. Discussion of several papers, grouped by Divisions.
d. Presented at the Atlanta (Ga.) Convention of the Society in February, 1954.
e. Presented at the Atlantic City (N.J.) Convention in June, 1954.

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